International Journal of Metallurgical &
Materials Science and Engineering (IJMMSE)
ISSN(P): 2278-2516; ISSN(E): 2278-2524
Vol. 5, Issue 1, Feb 2015, 31-38

THE EFFECT OF PEARLITE, CEMENTITE AND MARTENSITE PHASES ON VOLUMETRIC WEAR RATE OF HYPEREUTECTOID STEEL UNDER DRY SLIDING CONDITIONS

SHARANABASAPPA. M[1], V. R. KABADI[2] & VEERABHADRAPPA ALGUR[3]

[1]Department of Mechanical Engineering, Government Engineering College, Raichur, Karnataka, India

[2]Department of Mechanical Engineering, Basaveshwar Engineering College, Bagalkot Karnataka, India

[3]Department of Industrial and Production Engineering, Rao Bahadur Y Mahabaleshwarappa Engineering College, Bellary, Karnataka, India

ABSTRACT

Pin-on-disk unlubricated wear tests for 0.92 and 1.57 wt% C steel were conducted in moist air under loading between low and high operating conditions to investigate the effect of pearlite, cementite and martensite phases on volumetric wear rate. Also the effect of parameters such a sliding speeds and the normal pressures on volumetric wear rate was studied. Experimental results have shown that, the volumetric wear rate is minimum and almost constant for all the phases under all operational conditions for sliding speed 3m/s. Among the phases the combination of Cementite and Martensite of 1.57 wt% C has shown low volumetric wear rate. Because, this is the hardest specimen among the specimens. Cementite is the hardest phase which is reinforced in the martensite phase.

KEYWORDS: Cementeite, Hypereutectoid Steel, Martensite, Pearlite, Volumetric Wear Rate Etc

1. INTRODUCTION

In most of the mechanical parts of the assemblies there are some moving parts and some stationary. As a result of this there is a continuous relative sliding action in these mechanical devices. Frictional forces in these sliding surfaces result in wear. The friction and wear is not an intrinsic property of any material but it is a system property [1]. Friction and wear are responses of a tribo-system. Coefficients of friction and wear are parameters describing the state of contact of bodies in a tribo-system, and they are not material constants of the bodies in contact. They may be treated as material properties for technical conveniences with an engineering sense only in some special states of contact. Friction and wear, as two kinds of responses from one tribo-system, must be exactly related with each other on each state of contact in the system [2].

Wear may be defined as the unwanted removal of solid material from rubbing surfaces. It occurs when solid surfaces are in a sliding, rolling, or impact motion relative to one another. Now while this definition sounds quite simple, it does in fact lump together many quite, diverse phenomena such as abrasion, corrosion, galling, etc. in any particular instance of wear one may any of these mechanisms operating either singly or in combination.

It would seem, therefore that the better way to approach the problem of understanding and hence predicting wear is to recognize the fact the single term “wear” does in fact include at least four principle quite distinct and independent phenomena which have only the one thing in common, that their end result is the removal of solid material from the

rubbing surfaces. Hence rather than speaking simply of "wear" it will be helpful to our thinking if we recognize following distinct types of wear.

1.1 Types of Wear

1.1.1 Adhesive or Galling Wear

This wear caused due to relatives sliding or rolling movement of two mating metallic surfaces. If contact pressure are high it cause to permanent plastic deformation of rubbing component.

1.1.2 Abrasive Wear

It results when non metallic particles penetrate the metal surface and cause removal of metallic debris. Abrasive wear is a dominant failure mechanism of engineering components. The abrasive wear resistance in general increases with increase in hardness.

1.1.3 Corrosive Wear

The destruction of materials by the action of surrounding medium is called corrosion. Corrosive wear begins at the surface and gradually penetrates into the matrix.

1.1.4 Surface Fatigue

The removal of particles by cyclic processes comes under the category of fatigue wear. This type of wear predominates in most practical machine component.

1.1.5 Minor Types

These are the other types of wear except all of the above are called as minor types [3].

Wear conditions which influence significantly the wear of hyper-eutectoid steel include the vertical load, sliding velocity, ambient temperature and material. As a result, it seems appropriate to determine the wear mechanism of hyper-eutectoid steel from the property of the surface film such as oxide film on the worn surface and the metallographic structure of the pin and disk specimens. In this section, the wear mechanism of hyper-eutectoid steel is examined from these two points of view [4].

1.2 Historical Background

The history and development of hypereutectoid steel or ultrahigh carbon steel (i.e, steels containing between 1 and 2.1%C) are described. The early use of steel compositions containing carbon content above the eutectoid level is found in ancient weapons from around the world. For example, both Damascus and Japanese sward steels are hypereutectoid steels. Their manufacture and processing is of interest in understanding the role of carbon content in the development of modern steels. Although sporadic examples of UHCS compositions are found in steels examined in the early part of this century, it was not until the mid-1970s that the modern study began [5]. Over the past several decades, since initial studies by sherby et al. In the 1970s, ultra high carbon steels, which are hyper-eutectoid steel containing 1.0-2.1 wt% C, have been of great interest. The steels have a remarkable combination of mechanical properties, e.g. very high hardness, strength and wear resistance and good ductility at room temperature. The volume fraction of cementite in ultra high carbon steels is in the range of 15-32 wt %. Such a high volume fraction of carbides with high connectivity in the matrix makes these steels quite brittle after conventional solidification processes[6].

Investigation of hypereutectoid steels during the 1970s enabled the development of superplastic ultrahigh-carbon steels. Key to this development was the understanding of the equilibrium and kinetic aspects of cementite formation in carbon steels of hypereutectoid composition. Low alloy steels containing 1-2.1 wt% carbon, called UHCS, can be made superplastic by preventing the formation of a proeutectoid carbide network. Prevention of a proeutectoid carbide network also provides high strength and good ductility in UHCS materials. Several of the UHCS materials in these studies bear a remarkable similarity to the famous Damascus steels of historical significance. The similarity between UHCS and Damascus steels lies in their hypereutectoid composition. The majority of evidence indicates that ancient Damascus steels have typical carbon compositions of about 1.5wt% C.

In fact, when two surfaces are sliding against each other, most of the frictional work is turned into heat. The significant rise in temperature can modify the mechanical and metallurgical properties of sliding surfaces, and the wear behavior[7]. So, it is necessary to further investigate the wear behavior of different typical microstructures under different working conditions.

1.3 Conclusion of the Literature Survey

Hypereutectoid steel can achieve very high strength after severe plastic deformation because of the fine, stable substructures produce and are the most widely reported in the literature but the role of microstructure effects of several processes on the wear behavior have not been studied in enough detail. The hypereutectoid steel having a micro duplex structure might be applied to the construction, sliding parts of the machines etc in industry in the near future. Therefore it is required to study the effect of the microstructure on the wear behavior of hypereutectoid steels.

2. EXPERIMENTAL DETAILS

2.1 Selection of Steels for the Present Investigation

Considering the requirements of pearlite, cementite and martensite phases of the experimental steels, the percentages of carbon present in them were selected, approximately 0.92 and 1.57 wt% of carbon of the hypereutectoid steel respectively as shown in table 2.1. The samples of size 30 mm lengths and 10 mm diameter in the form of pins were used.

Table 2.1: The Chemical Composition of the Hyper Eutectoid Steel (wt-%)

Sl. No	% C	% Si	% Mn	% P	% S
1	0.920	0.256	0.348	0.002	0.002
2	1.573	0.265	0.549	0.026	0.021

The steel samples were subjected to various heat treatment processes to attain variety of microstructures. The wear characteristics of heat- treated samples were investigated. Initially all the experimental carbon steel were annealed under the charcoal cover for avoiding decarburization and develop the equilibrium pearlite ,cementite and martensite phases.

The specimens were heated at 775°C soaked for two hour for homogenization and cooled in furnace. This process results to the formation of Pearlite and Cementite. The specimens were heated at 740°C and soaked for one hour for homogenization and quenched in water. This hardening process led to the formation of martensite and Cementite. The specimens were heated again to 950°C and soaked for two hour for homogenization and quenched in water. This hardening process led to the formation of martensite.

2.2 Wear Test

Dry sliding wear test was carried out using a hardened counter face of a polished disk of EN-32 with a hardness of HRC 62-65 at a relative humidity of 50-70% at a room temperature of 32°C. A pin-on-disk type wear testing machine manufactured by DUCOM, Bangalore (India) was used here. A pin specimen of hyper-eutectoid steel is pressed against a rotating disk specimen of carbon steel for machine structure use. Weight losses of pin were recorded using an electronic balance having an accuracy of 10^{-7} Kg at different interval of time. Test were carried out at the normal pressures from 0.1249,0.3747,0.6245 and 0.8743 M Pa with the sliding speeds of 1m/s, 3m/s, 5m/s and 7m/s for a sliding distance of 10,000 meters. The volumetric wear rate was calculated from the expression volume loss per unit sliding distance (mm^3 / m). A schematic diagram of wear testing machine is shown in Figure 2.2.

Figure 2.2: Pin on Disk Machine

3. RESULTS AND DISCUSSIONS

3.1 Volumetric Wear Rate

After the every wear test, weight loss was estimated for every speed and normal load. During the sliding, the pin actually rest on few asperities. For a small normal load also, the stress on the asperity is very high. During initial wearing, this normal load and the tangential force due to the rotary motion of the disc will act on the rubbing surface. Initially this normal load and tangential stress will bear by the few asperities. As the time passes the growth of the asperities will takes place and result in increase in the height of the asperity as well as area of the asperities. As the height of the asperity increases the effective torque on the asperity will increase for the same tangential force on the asperity. Once this increased torque will not bear by the asperity then the asperity will break and rolls between the wearing surfaces. During rolling of the asperity, the asperity losses its sharp corners and result in low abrasive wear. The growth of the asperity is depends upon the time rest between the wearing pin and with the sliding disc. As the speed increases the residential time will decrease hence the growth of the micro weld will decrease and result in low loss of the material i.e., low wear rate. Also actually with increase in the sliding speed the effective normal load on the wearing surface will also decrease this is due to the bournouli’s theorem. This is also a reason to decrease in the wear loss with increase in the sliding speed.

During wearing at the interface, plastic deformation of the wearing surface takes place. During plastic deformation, the surface becomes hard due to the strain hardening. With increase in the hardness the wear loss will decrease. Also during wearing the frictional temperature generates. The bulk frictional temperature is low, if it is measured by any one method. But the flash temperature i.e., the actual temperature at the contact region is quite high and this result

in softening the material. Due to this softening action the wear loss will increase. During wearing, the generated heat loss takes place due to the conduction and convection. If the rate of heat loss is more than the rate of heat generation then the frictional temperature will not affect on the wearing surface and result in work hardening. If the rate of heat generation is more than the rate of heat loss then the sufficient heat collected on the wearing surface and result in softening effect of the wearing surface.

3.1.1 Effect of Normal Pressure

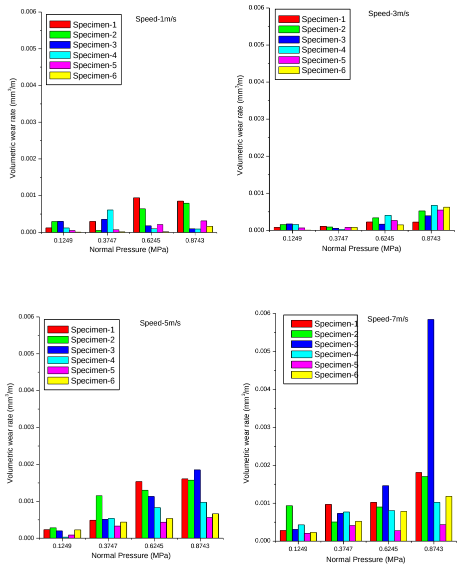

Figure 3.1.1: Effect of Normal Pressure on Volumetric Wear Rate for the Sliding Speeds of 1, 3, 5 & 7 m/s for all Specimens

From Figure 3.1.1, it is observed that, under low operational conditions volumetric wear rate is low. But higher volumetric wear rate is observed under high operational conditions. Volumetric wear rate is increased with increasing the normal pressure. Combination of pearlite and cementite is nothing but combination of ferrite and cementite. Cementite is quite hard phase compared with the ferrite phase. Initially ferrite phase wears faster than the cementite. When cementite phase comes in contact with the sliding disc, cementite breaks and overlays the wearing surface. Hence, volumetric wear rate is low when compared with the martensitic steel. Under high normal pressure, these broken cementite thrown away in the form of wear debris and again ferrite phase come in contact with the sliding disc. So the volumetric wear rate is increased with the normal pressure.

Also It is observed that, with increase in the normal load at the particular sliding speed, the volumetric wear rate is increased for all the specimens. An increase in the wear rate takes place with an increase in load and tangential velocity, reaching a maximum value and leading to a change in wear surfaces and wear debris from the presence of oxide to the presence of metallic particles. For loading conditions above the maximum in wear rate, plastic deformation of the sliding surfaces is predominant. Large metallic particles adhered to the surface, act as hard sliders and produce grooves as shown in Figure 3.2.1. The deformation wear debris cause their hardening and fracture, and their rolling forms cylindrical are spherical shaped debris. These characteristic allow for classifying the mechanism as adhesive wear. Which is in accordance with previous approaches [8].

From the figure, it is observed that volumetric wear rate of 100% martensite which was developed from 0.92%C is high under high sliding speeds of 5 and 7 m/s. The water quenched specimen were associated with macro cracks. These macro cracks would lead to impact wear are macro spalling of the specimen. The wear rate increases with increasing normal pressure, this is due to the fact as the normal pressure increases frictional heat generates at the contact surface and hence the strength of the material deceases [9].

3.1.2 Effect of Sliding Speed

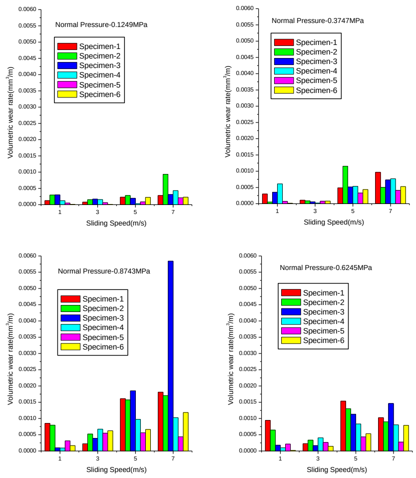

Figure 3.1.2: Effect of Sliding Speed on Volumetric Wear Rat for the Normal Pressure 0.1249, 0.3747, 0.6245, & 0.8743 M Pa for all Specimens

From the figure 3.1.2 it is observed that, volumetric wear rate is least at the sliding speed of 3 m/s for all the normal pressure and for all the specimens. Also by observing the figures clearly, the normal pressure of 0.3747 MPa, the volumetric wear rate is almost low for all the sliding speeds and specimens. However, the values of the transition loads were strongly affected by sliding speed and at many speeds only one transition was encountered [10].

To obtain a better understanding of the relationship between microstructure and wear behavior of materials and to reveal the micromechanism of sliding wear, at a sliding speed of 3 m/s and 0.3747 MPa. It can be seen that the volumetric wear rate is very small for the different microstructures. However, only a slight difference in volumetric wear rate is found for different microstructures.

After the transition from mild to severe wear, a considerable difference in volumetric wear rate for specimens with different microstructures was observed. The wear resistance of different microstructures increased in the following order, fully martensite, pearlite + cementite and martensite + cementite. Among the phases the combination of Cementite and Martensite of 1.57 wt% C has shown low volumetric wear rate. Because, this is the hardest specimen among the specimens. Cementite is the hardest phase which is reinforced in the martensite phase. Generally, carbon is the most important element profoundly affecting the mechanical properties of the steels. Increasing the carbon content of the steels increases the hardness and strength. More-over, plain carbon steels have moderate strengths and can resist satisfactorily ordinary temperatures and atmospheres [11]. The Volume loss is directly proportional to the normal load, sliding distance and inversely proportional to the hardness of the material according to the Archard's equation. If still hardness increases, the volume loss may decrease due to its brittleness. Almost all brittle materials have low shear strength hence during the

wear material failure occurs due to the low shear stress of the material. It is well known that the hardness of a materials is a major wear parameter in Archard's wear equation [12]. The hardness of the material is a dominant parameter affecting the wear rate, which is consistence with the observation by Rabinowicz and Archard's wear law is valid and gives the form V = kPL/H, where V is the volume loss, k is a wear coefficient, L is the sliding distance, P is the normal load and H is the hardness.

3.2 Scanning Electro Microscope Studies

In case with low sliding speed under low normal pressure the corresponding wear mechanism involved are mostly adhesive. Figure 3.1.1 shows the worn surface of specimen after wear test at applied normal pressure of 0.8743 MPa and sliding speed of 1 m/s, adhesive wear mechanism is observed by Figure 3.2.1 and Figure 3.2.2 Adhesive wear occurs mostly on the clean surface and the same becomes prominent due to formation of micro welds at highly localized pressure contacts and subsequent rupturing of the same and hence the corresponding wear loss is high.

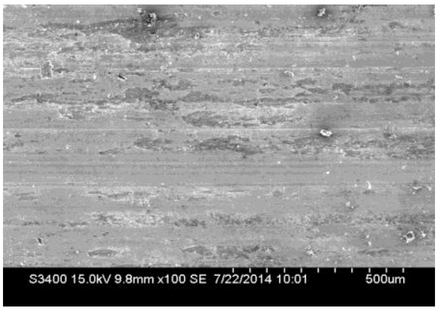

Figure 3.2.1: SEM Micro Graph of Sp-1, Speed-1m/s, Nor. Pr. 0.8743 MPa

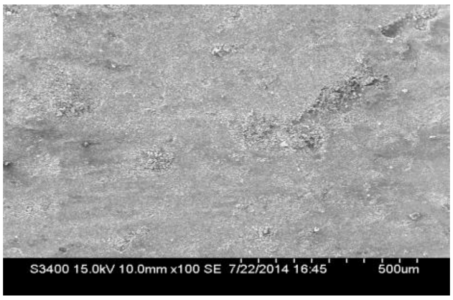

Figure 2: SEM Micro Graph of Sp-4, Speed-1m/s, Nor. Pr. 0.1249MPa

4. CONCLUSIONS

Based on the experimental observations, the following conclusions can be drawn.

- The volumetric wear rate is mainly affected by combinations of phases.
- For all hard materials, the dynamic frictions were initially low.
- The wear rate of contact surface after a change in load to a high level is affected by the rubbing history associated with the load and sliding speed.
- In the transition regime, the volumetric wear rate is constant irrespective of normal pressure for all specimens.
- The volumetric wear rate is minimum and almost constant for all the phases under all operational conditions for sliding speed 3m/s.

- Among the phases the combination of Cementite and Martensite of 1.57 wt% C has shown low volumetric wear rate.

REFERENCES

1. P. R. Gangasani, 'Friction and wear characteristics of ductile iron in dry sliding conditions', Keith millis symposium on ductile cast iron', 2003,
2. Koji kato*, 'Wear in relation to friction –a review', Wear 241 (2000) 151-157.
3. Jhon T. Burwell, Jr.* 'Survey of possible wear mechanisms', American-standard corp., New York, N. Y. (U. S. A), vol. 1(1957/58), 119-140.
4. Etsuo Marui, Norihiko Hasegawa, Hiroki Endo, Katsuhito Tanaka, Taiji Hattori. 'Research on the wear characteristics of hypereutectoid steel'. Wear 205 (1997) 186-199.
5. J. Wadsworth, O. D. Sherby. 'The history of ultrahigh carbon steels'. The metallurgical society 1997 Materials week Indianpolis, IN September 14-17, 1997.
6. K. P. Liu[a] , X. L. Dun[a], J. P. Lai[a], H. S. Liu[a,b,]*, 'Effect of modification on microstructure and properties of ultra high carbon (1.9 wt % C) steel', Materials Science and Engineering A 528 (2011) 8263-8268.
7. You Wang[a,b,c*], Tingquan Lei[a], Jiajun Liu[b], 'Tribo-metallographic behavior of high carbon steels in dry sliding II. Microstuctur and wear'. Wear -231(1999)12-19.
8. M. C. M. Farias*, R. M. Souza, A. Sinatora, D. K. Tanaka, 'The influence of applied load, sliding velocity and martensitic transformation on the unlubricated sliding wear of austenitic stainless steels', Wear 263 (2007) 773-781.
9. M. A. Chowdhury*, M. K. Khalil, D. M. Nuruzzaman, M. L. Rahaman. **'**The Effect of Sliding Speed and Normal Load on Friction and Wear Property of Aluminum', International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS Vol: 11 No: 01 53-57.
10. N. C. Welsh. 'The dry wear of steels 1. The general pattern of behaviour'. Research laboratory, vol. 257. A.1077 Published 7th January, 1965, 31-50.
11. Amit K Gupta[1], 'Deep Narayan Mishra[2], An experimental investigation of the effect of carbon content on the wear behaviour of plain carbon steel', IJSR vol.2 issue7, July (2013) 222-224.
12. Z. F. Zhang, L. C. Zhang*, Y.-W. Mai. 'Particle effects on friction and wear of aluminium matrix composites', Journal of materials Science 30 (1995)5999-6004.